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Influence of Asymmetry on the Flexion Relaxation Response of the Low Back Musculature

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Abstract

Background: The flexion relaxation phenomenon has been extensively studied in sagittally symmetric postures. Knowledge about this phenomenon in asymmetric trunk postures is less well understood, and may help to reveal the underlying physiology of the passive tissue/active tissue load-sharing mechanism in the lumbar region.

Methods: Twelve participants performed fifteen controlled, full range trunk flexion–extension motions toward three asymmetric lifting postures (0° (sagittally symmetric), 15°, and 30° from the mid-sagittal plane). The electromyographic activity data from the paraspinals at the L3 and L4 levels and trunk kinematics data from motion sensors over the C7, T12 and S1 vertebrae were recorded. The lumbar flexion angles at which these muscles' activities were reduced to resting levels during forward flexion provided quantitative data describing the effects of asymmetry on the passive tissue/active tissue interaction.

Findings: Flexion relaxation was observed in the muscles contralateral to the direction of the asymmetric trunk flexion motion. The response of the ipsilateral extensor musculature was much less consistent, with many trials indicating that flexion relaxation was never achieved. Increasing asymmetry from 0° to 30° led to a 10% reduction in the maximum lumbar flexion. Lumbar flexion angles necessary to achieve flexion relaxation in the contralateral muscles also decreased (L4 paraspinal-related angle decreasing by 15% and the L3 paraspinal-related angle decreasing by 21%).

Interpretation: Under asymmetric conditions the lumbar flexion angle at which the transition from active muscle to passive ligamentous extension moment is altered from that seen in symmetric motions and this transition can have implications for the loading of the spine in full flexion (or near full flexion) postures

Key words: Lumbar spine; Flexion relaxation phenomenon; Asymmetric bending

1. Introduction

Lumbar region anatomy, physiology and biomechanics have been widely investigated to understand the mechanism of low back injury. These studies have shown that both active tissues and passive tissues play important roles in providing the necessary restorative moments and thereby loading of the lumbar spine during trunk flexion and extension exertions. Due to the large number of degrees of freedom of the system and the complex interactions among the structures, our understanding of the load sharing mechanisms in this region is still far from complete. At the most basic level, researchers have long recognized the transition that takes place during a slow, controlled motion from upright to a full flexion position. This process involves the transfer of the role of extension moment generator from the active mechanism (muscle tissue) to the passive mechanism (ligaments, discs and fascia). This response can be seen by observing the reduction and eventual elimination of the electrical activity of the erector spinae muscles as the trunk flexes to the full flexion posture and was described as the flexion relaxation phenomenon (FRP) by Floyd and Silver (1951, 1955). Understanding how lifting task variables can influence this FRP response may provide insights into the underlying mechanism load sharing and injury risk to both the passive and active tissues of the lumber region.

Previous studies have shown that FRP is affected by a number of relevant lifting task variables including magnitude of external load (Schultz et al., 1985), the speed of motion (Sarti et al., 2001), body posture and motion during sagittally symmetric trunk flexion and extension (McGorry et al., 2001), low back muscle fatigue (Descarreaux et al., 2008), passive tissue creep introduced by prolonged trunk flexion (Solomonow et al., 2003; Shin et al., 2009) , repetitive flexion (Dickey et al., 2003; Olson et al., 2004), and previous low back disorder (Shirado et al., 1995). To date, all previous studies have focused on the responses of the FRP in sagittally symmetric motions, but there is ample evidence in the archival literature to suggest that asymmetric postures may impact the FRP. Previous studies have shown that lateral bending and axial rotation of the lumbar spine creates non-linear (sometimes exponentially increasing) passive resistance (e.g. McGill et al., 1994; Boden and Oberg, 1998; Adams and Dolan, 1991). McGill and colleagues (1994) used a frictionless jig to quantify the passive stiffness of the lumbar torso in both lateral bending and axial twisting and showed nonlinear increases in stiffness and strain energy with increasing deviations in each of these cardinal planes of motion. These results would indicate that during asymmetric lifting, passive resistance created by the rotation and lateral flexion of lumbar vertebra must be overcome by the activation of lumbar musculature, which, in turn, can have a direct impact on their FRP response. In addition, simple differences in muscle activation profiles between ipsilateral and contralateral back muscles during asymmetric lifting have also been observed (e.g. Marras and Mirka, 1992). These most basic differences in muscle activation strategies may likewise influence the onset and duration of the FRP of these bilateral muscles. The objective of current study was to investigate the effect of asymmetric trunk postures on the flexion relaxation phenomenon of the low back musculature. We hypothesize that asymmetric lifting postures will reduce the onset angle of the FRP and we seek to quantify the magnitude of these changes through this work.

2. Methods

2.1 Participants

Twelve participants with average age 26.2 (SD 2.9) years, height 178.2 (SD 5.0) cm and total body mass 70.6 (SD 5.3) kg were recruited from the student population of Iowa State University. Subjects with a history of chronic low back pain, chronic lower extremity injury or currently experiencing discomfort in these regions were excluded from participation. All participants provided written informed consent prior to participation and all procedures were reviewed and approved by the Institutional Review Board for the Use of Human Subjects in Research.

2.2 Data Collection Instrumentation

A surface electromyography (EMG) data collection system (Model: Bagnoli, Delsys Inc, Boston, MA, USA) employing four bipolar surface EMG electrodes were placed bilaterally over the L4 and L3 lumbar vertebrae levels of the paraspinal muscles. The sampling locations were 2 cm lateral from L4 spinous process and 4 cm lateral from L3 spinous process, respectively. These data were collected at 1024 Hz. Trunk kinematics data were collected using a magnetic field-based motion tracking system (Model: Motion Star, Ascension Technology Corporation, Burlington, VT, USA). Three sensors were secured to the skin over the C7, T12 and S1 vertebrae respectively, and these data were collected at 102.4 Hz. Data acquisition software (MotionMonitor, Innovative Sports Training, Chicago, IL, USA) was used to collect and synchronize EMG and kinematics data.

2.3 Experimental Apparatus

An asymmetric reference frame (ARF) was used to provide a stable system for securing the pelvis during all experimental tasks. A lumbar dynamometer (Model: Kin/Com, Chatanooga Group, Inc., Hixson, TN, USA) was used in conjunction with the ARF to provide static resistance and control of trunk flexion angle during the trunk muscle maximum voluntary contraction (MVC) exertions (Mirka and Marras, 1993). During the experimental trials, the subjects utilized a series of vertical cues (vertically standing 2x4 boards) to maintain the required asymmetric postures through the full range of trunk flexion (Figure 1).

Insert Figure 1 about here

2.4 Experimental Design

The independent variable in this study was trunk asymmetric angle (ASYM) and was considered at three levels: 0^o (sagittally symmetric), 15^o and 30^o (both leftward twisting in transverse plane from mid-sagittal plane). This asymmetric angle was defined as the angle between the mid-sagittal plane and the plane containing a vertical line running through the midpoint between the ankles and the midpoint between the hands in the full flexion posture (Waters et al., 1993).

There were ten dependent variables in this study and they can be divided into two categories: lumbar flexion angle (a local measure) and trunk inclination angle (a global measure) (Figure 2). Lumbar flexion angle measures were defined as the difference between the T12 sensor and the S1 sensor in the plane of motion (using the "pitch angle" of the motion sensors). Natural upright posture creates a negative value for this measure because of the lumbar lordosis. Trunk inclination angle measures were defined as the location of the C7 sensor relative to the S1 sensor (using the X-Y-Z global coordinates of the two sensors). Natural upright posture creates near zero value for this measure.

Insert Figure 2 about here

The first two dependent variables described the trunk posture at full, relaxed trunk flexion. These measures include the peak lumbar flexion angle and the peak trunk inclination angle. The remaining eight dependent variables similarly used the sensors to define the relevant angles, but instead of being defined at the full, relaxed flexion position, were instead defined as the angles at which the individual extensor muscles turned "OFF" during the trunk flexion motion. The methods of finding this EMG-Off point for each of the muscles is described in greater detail in the Data Processing section, but for current purposes, the EMG-Off point can be described as the point at which the muscle's activity level was indistinguishable from the full flexion, resting value (Figure 3). Each muscle has the potential to turn off at different trunk angles, therefore the eight variables are: right L4 paraspinals lumbar flexion angle; right L4 paraspinals trunk inclination angle; right L3 paraspinals lumbar flexion angle; right L3 paraspinals trunk inclination angle; left L4 paraspinals lumbar flexion angle, left L4 paraspinals trunk inclination angle; left L3 paraspinals lumbar flexion angle; and left L3 paraspinals trunk inclination angle.

Insert Figure 3 about here

2.5 Protocol

Upon arrival the experimental procedures were described to the participant and written informed consent was obtained. Basic anthropometric data were gathered and a five minute, lower extremity/torso warm-up routine was followed. Surface electrodes and motion sensors were then secured in the appropriate locations.

The experimental procedures began with the participant performing maximum voluntary contraction (MVC) trunk extension exertions (standing, 20^o sagittal flexion, pelvis secure) against the static resistance provided by the ARF dynamometer following the procedures described in Mirka and Marras (1993). During these exertions EMG data were collected for all muscles. After these MVC trials were completed, 15 trunk flexion-extension trials (five repetitions for each of the three asymmetric angles) were performed in a randomized order. At the beginning of each trial the participant was told of the asymmetry to be maintained during that trial. The participant rotated their torso in the transverse plane to the required angle and then slowly lowered their torso using the wooden guides to maintain the required rotational angle. In all conditions the pace of the motion was set as: seven seconds to move from upright to full flexion; six seconds of maintaining full flexion posture (including an exhale); and another seven seconds to move from full flexion to the upright posture. A metronome was used to assist the participants in maintaining the appropriate pace during the flexion-extension motion. After the exhale in the full flexion posture, a trigger was activated to indicate the timing of the full flexion posture. This trigger point data point was used in the data analysis process.

2.6 Data Processing

The EMG data from the four muscles were digitally filtered using a low-pass filter of 500 Hz, a high-pass filter of 10 Hz and the signal was notch filtered at 60 Hz (ambient electrical noise) and 102.4 Hz (motion tracking system) and their aliases. Standard deviation (SD) profiles of these filtered (unrectified) EMG data for each muscle were developed by calculating the standard deviation in a moving data window of 512 data points (Figures 3 and 4.) The value of this standard deviation for the 512 datapoints after the trigger point was described as the full-flexion standard deviation (FSD). If this FSD was of sufficient magnitude that the SD value during the seven second trunk flexion motion never reached 4*FSD, it was determined that FRP was never reached (example in Figure 4). If the SD profile during the trunk flexion motion did reach this 4*FSD value during the seven second flexion motion, the first instance during the trunk flexion motion when the SD value was less than 3*FSD was determined to be the EMG-Off- point for that muscle (example of this case in Figure 3). The lumbar flexion angle and trunk inclination angle values corresponding with this instant in time were found (Figure 3).

Insert Figure 4 about here

2.7 Statistical Analysis

Prior to any statistical analysis, the assumptions of the analysis of variance (ANOVA) procedures (homogeneity of variances of the residuals, residuals normally distributed, and independence of observations) were evaluated using the techniques advocated by Montgomery (2005). Once these assumptions were verified, multivariate analysis of variance (MANOVA) was performed to evaluate the effects of ASYM on the set of dependent variables collectively, thereby controlling for the experiment-wise error rate. Univariate ANOVA procedures were then conducted and a Tukey-Kramer post-hoc test was performed to further explore the significant effects. The criteria p-value of $p<0.05$ was used for all statistical tests. As will be seen in the Results section, the number of times where EMG-Off occurred in the ipsilateral muscles was sufficiently small (FRP not observed), that this statistical analysis was only conducted to evaluate the effect of ASYM on the trunk and lumbar angles associated with the EMG-Off for the right side(i.e. contralateral) muscles.

3. Results

The results show that in the sagittally symmetric condition (0^{o}), all muscles consistently demonstrated the flexion relaxation phenomenon, confirming the results shown by most previous research in this area. In contrast, under the asymmetric conditions the ipsilateral muscles showed a marked reduction in the prevalence of the FRP (Table 1). Further, the fraction of trials wherein FRP occurred decreased significantly for these ipsilateral muscles with increased asymmetry, to the extreme situation wherein FRP never occurred in the ipsilateral L3 paraspinal in the 30° condition. Also noteworthy are the higher FRP prevalence rates for the ipsilateral L4 paraspinals as compared to the ipsilateral L3 paraspinals, indicating a potential coronal plane moment arm effect.

Insert Table 1 about here

Results of the MANOVA showed a significant effect of ASYM ($p<0.001$) and the univariate ANOVA results showed that these effects were broadly significant (all results presented here showed p-values <0.001). On average, there was a 3° decrease in the peak lumbar flexion angle and a 3.5° decrease in the peak trunk inclination angle when asymmetry increased from 0 degrees to 30 degrees (Figure 5). Similarly when considering the contralateral L4 and L3 paraspinals, increases in asymmetry consistently reduced the lumbar flexion angles at which the flexion relaxation response was being elicited (3.8° reduction for the right L4 paraspinals and 5° reduction for the right L3 paraspinals) and trunk inclination angles followed a similar pattern (Figures 6 and 7).

Insert Figures 5 through 7 about here

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4. Discussion

The flexion relaxation phenomenon documents the natural transition from active to passive extension moment by showing the reduction and eventual elimination of the muscle activities of the trunk extensors as a person bends to a full trunk flexion posture. In sagittally symmetric postures, the sagittal plane moment arms of these passive structures are constant bilaterally and there is a clear bilateral sharing of this extensor moment. The results of the sagittally symmetric trials in the current study support this assertion and, after controlling for differences in the techniques for measuring lumbar and inclination angles, are consistent with previous studies of symmetric FRP (e.g. Solomonow et al., 2003). During asymmetric bending tasks, however, the moment arms of these tissues about the spinal column are not the same and this imbalance proved to be the source of interesting changes in the FRP during asymmetric bending in the current study.

During an asymmetric trunk flexion exertion the motion of lumbar spine is a combination of axial rotation, lateral bending and anterior flexion (as illustrated in Figure 1). From a purely geometric point of view, trunk flexion in asymmetric postures creates angular motion in the coronal plane (lateral flexion) which will generate greater passive tissue tension contralaterally and this tension is in direct proportion to the lateral distance of these passive tissues from the spine (their coronal plane moment arm about the spine). With a greater moment arm the passive tissues on the contralateral side are placed in tension earlier in the flexion motion than they would be in the sagittally symmetric postures. This underlying mechanism is supported by our results showing that both peak lumbar flexion angle and peak trunk inclination angle were significantly decreased with greater asymmetry and is similarly supported by the loss of the FRP of the ipsilateral muscles.

These coupled spinal motions also create important left side-right side differences in the degree to which these passive tissues are placed in tension and thereby where the FRP is likely to begin. In the current study, the right side lumbar tissues (contralateral to the direction of asymmetric trunk flexion) generated greater tension than the left side tissues because of the coronal plane (lateral) motion. This led to important differences in the prevalence of flexion relaxation (Table 1) as well as differences in the lumbar and trunk angles at which these muscles turned off (Figures 6 and 7) as a function of both left vs. right as well as medio vs. lateral location of the muscles.

In addition to the purely geometric point of view, the differential responses of the contralateral L4 paraspinals and L3 paraspinals can also be considered relative to the functions of the local and global muscle distinction proposed by Bergmark (1989). In Bergmark's model, the multifidus muscles are considered local muscles and are tasked with providing lumbar spinal stiffness and stability (supported by Ward et al., 2009), while the longissimus thoracis are considered global muscles and provide trunk extension moment. In the current study the L4 paraspinal sampling location is 2cm from the centerline of the spine and therefore the EMG data are mainly gathered from muscles that are very close to the spinal column (similar to multifidus in the Bergmark model). These muscles therefore provide significant lumbar spinal stiffness and stability. On the other hand, paraspinal muscles sampled at the L3 level (4cm from centerline of spine) are more similar in function to the longissimus and serve as global muscles providing trunk extension moment. Under conditions of relative instability one might expect the local muscles to remain active while the global muscles could reduce activity if the external moment is countered by the passive tissues. Figures 6 and 7 show that the contralateral L4 paraspinals turned off later in the asymmetric trunk flexion movements than did the L3 paraspinals, providing support for "local vs. global" muscle distinction as a potential contributor to the recorded changes in the flexion relaxation response in the asymmetric postures.

The relevance of the results of this study is particularly clear for spine modelers that use the EMG-assisted modeling approach. The results of this study provide quantitative data regarding the effects of asymmetry on the degree of trunk flexion required to completely eliminate the active component for the trunk extensor mechanism. Future analyses will seek to identify the specific trunk flexion angles at which the active tissues begin to reduce activation levels and commence the process of transitioning the required moment to the passive tissues. Once these boundaries are clearly established, the quality of the loading predicted using these EMG-assisted modeling techniques can be improved by more appropriate partitioning of the active-passive tissue loading. From an ergonomics perspective, the importance of these results is noted for those work tasks requiring full, or near-full, trunk flexion postures. Often these postures are coupled with asymmetric lifting exertions and the interplay between the passive and active tissues has implications not only for compression loading, but also anterior-posterior and lateral shear loading as often these tissues have a complex three-dimensional vector line of action. Models providing more accurate estimates of spinal and tissue loading may result in a better understanding of the etiology of injuries of the low back.

5. Conclusions

This study showed that peak lumbar flexion angle and peak trunk inclination angle both decreased with increases in trunk asymmetry. Lumbar muscles on the ipsilateral side (same side as the asymmetric posture) often did not achieve flexion relaxation and muscles on the contralateral side showed a significant effect of the magnitude of the asymmetry on the trunk flexion angles at which the flexion relaxation occurred. These results collectively provide support for a relationship between the medio-lateral location of back muscles and EMG-Off point for these muscles. The results of this study provide quantitative data describing the active-passive load-sharing mechanism at work in the lumbar region.

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Table 1: Percent of trials showing FRP by muscle and asymmetry condition. (Right-side muscles were contralateral to the direction of the asymmetric trunk flexion.)

Asymmetry	L4 paraspinals		L3 paraspinals	
	Right	Left	Right	Left
0°	100.0	100.0	100.0	100.0
15°	96.7	76.3	96.7	35.6
30°	98.3	47.5	98.3	0.0

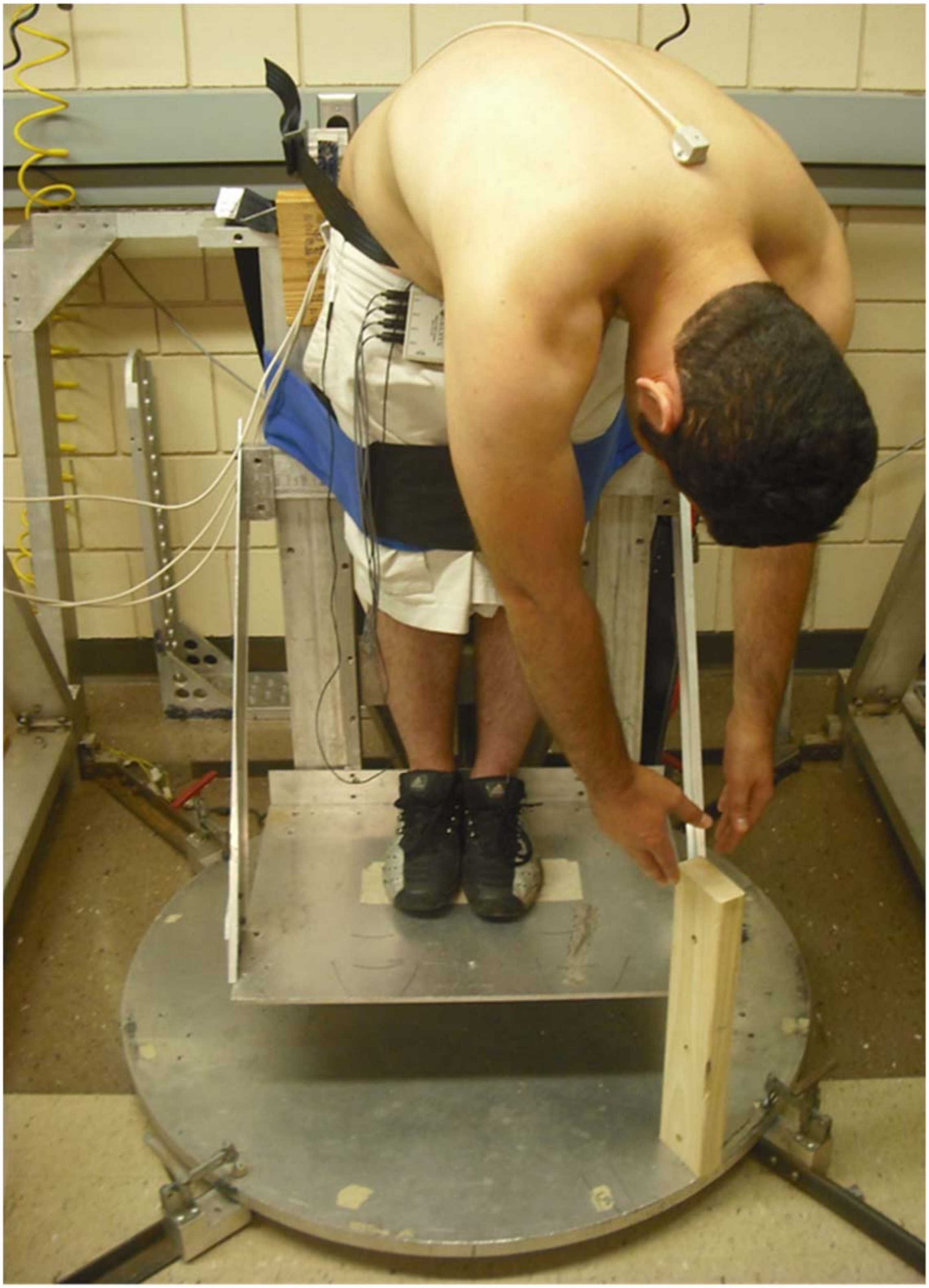

Figure 1: Experimental apparatus.

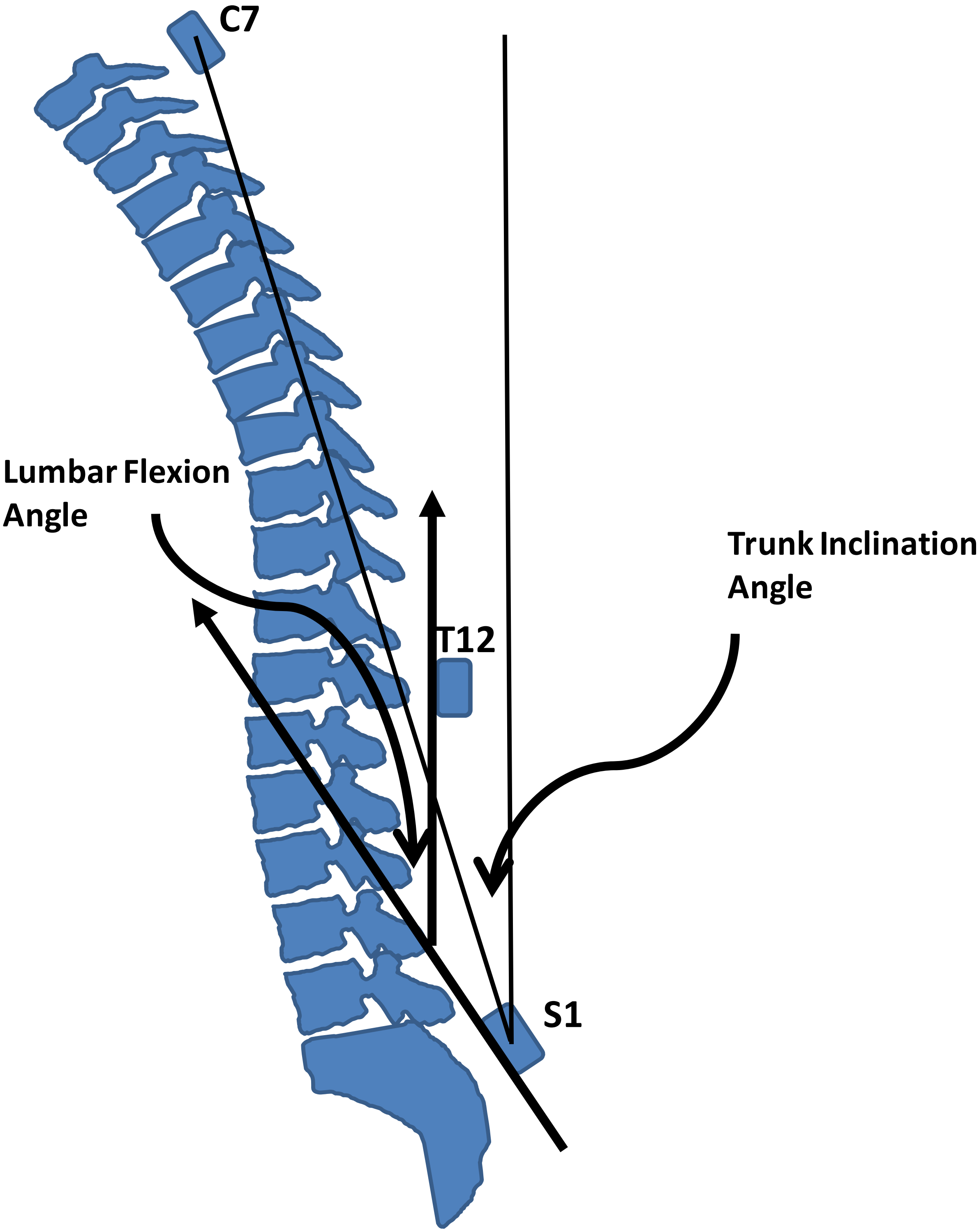

Figure 2: Definition of lumbar flexion angle and trunk inclination angle.

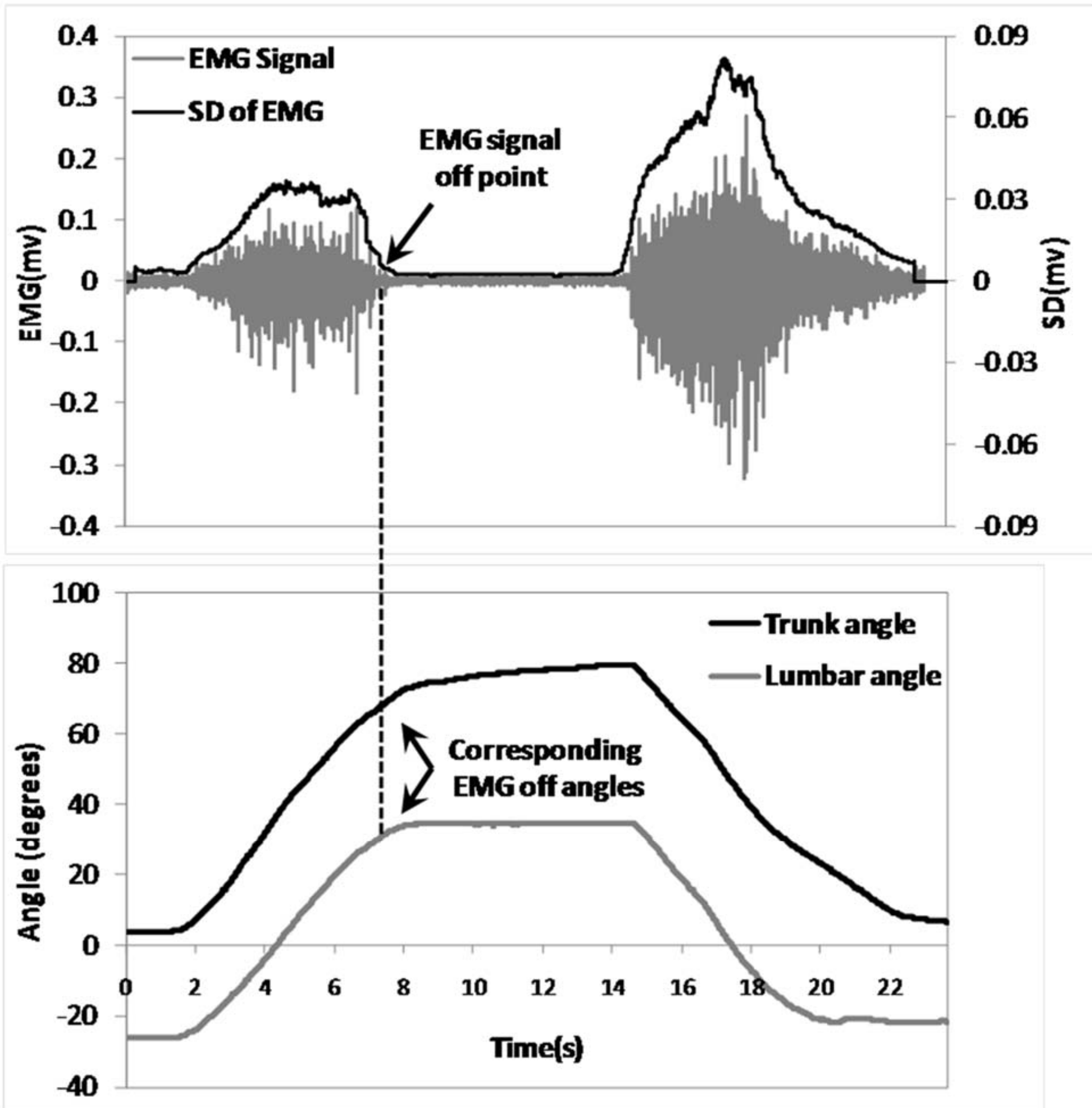

Figure 3: A typical profile of lumbar flexion angle, trunk inclination angle, EMG signal, and standard deviation of the EMG signal.

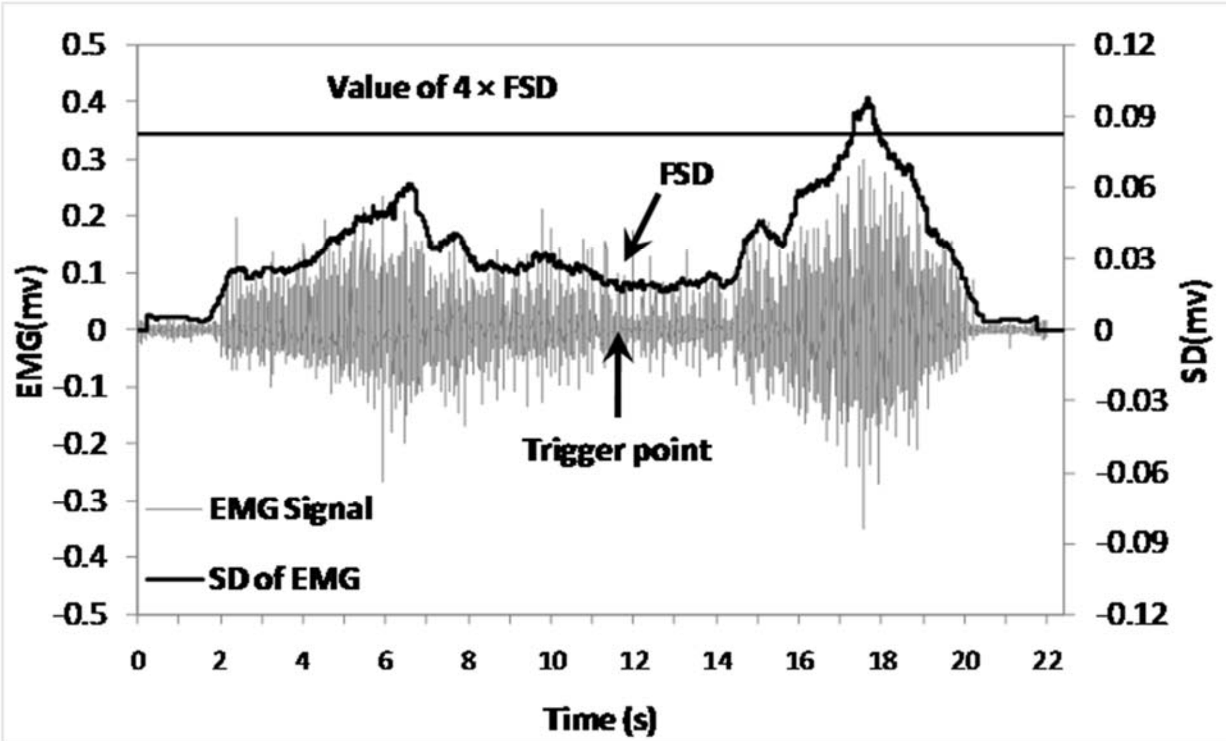

Figure 4: An example of an EMG profile that the data processing algorithm would have classified as having not ever reached flexion relaxation.

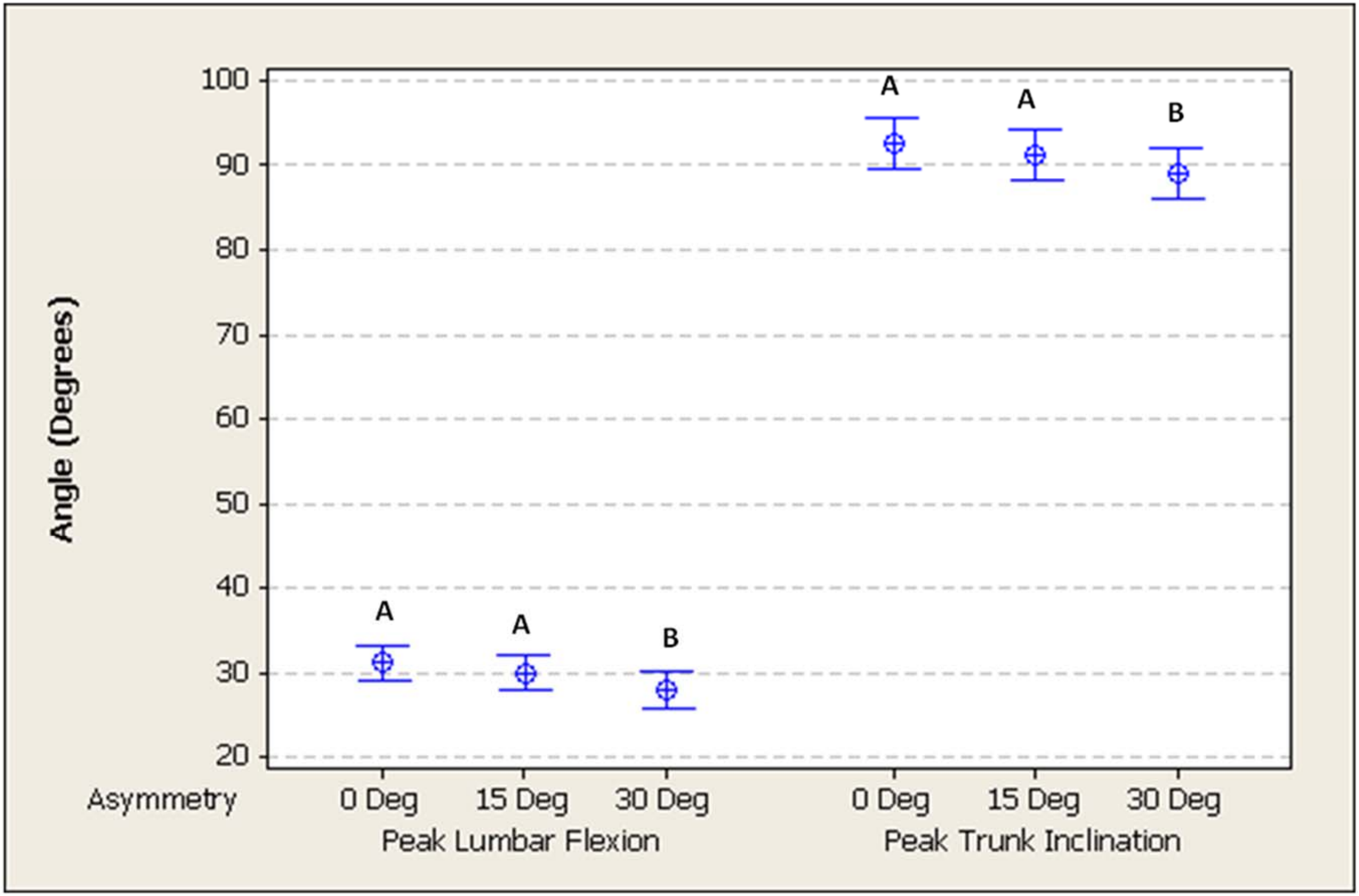

Figure 5: Peak lumbar flexion angle and peak trunk inclination angle as a function of asymmetry. Different letters indicate levels that are significantly different and 95% confidence interval is shown.

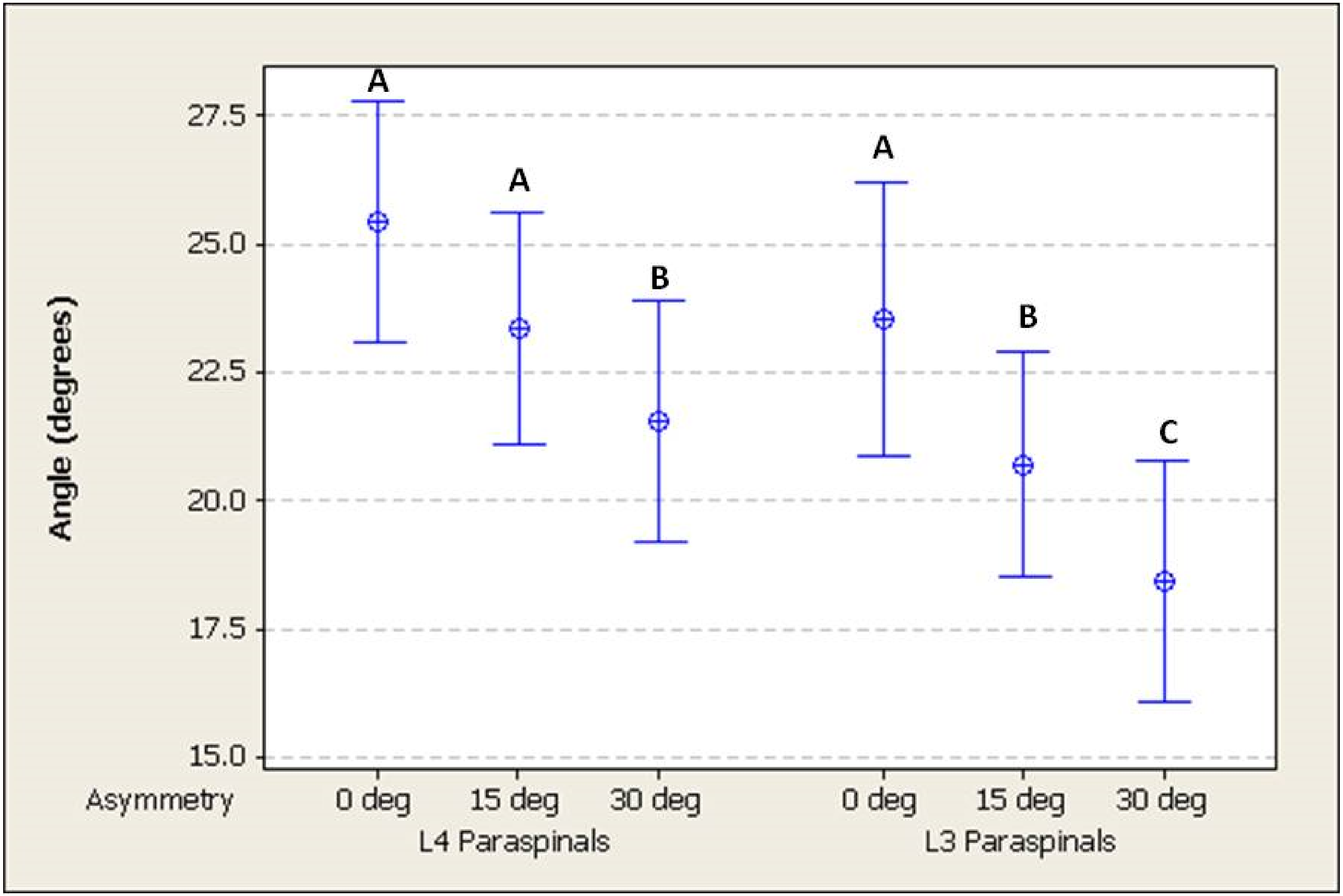

Figure 6: Lumbar flexion angle at EMG-Off point for of each of the contralateral (right side) lumbar muscles as a function of asymmetry. Different letters indicate levels that are significantly different and 95% confidence interval is shown.

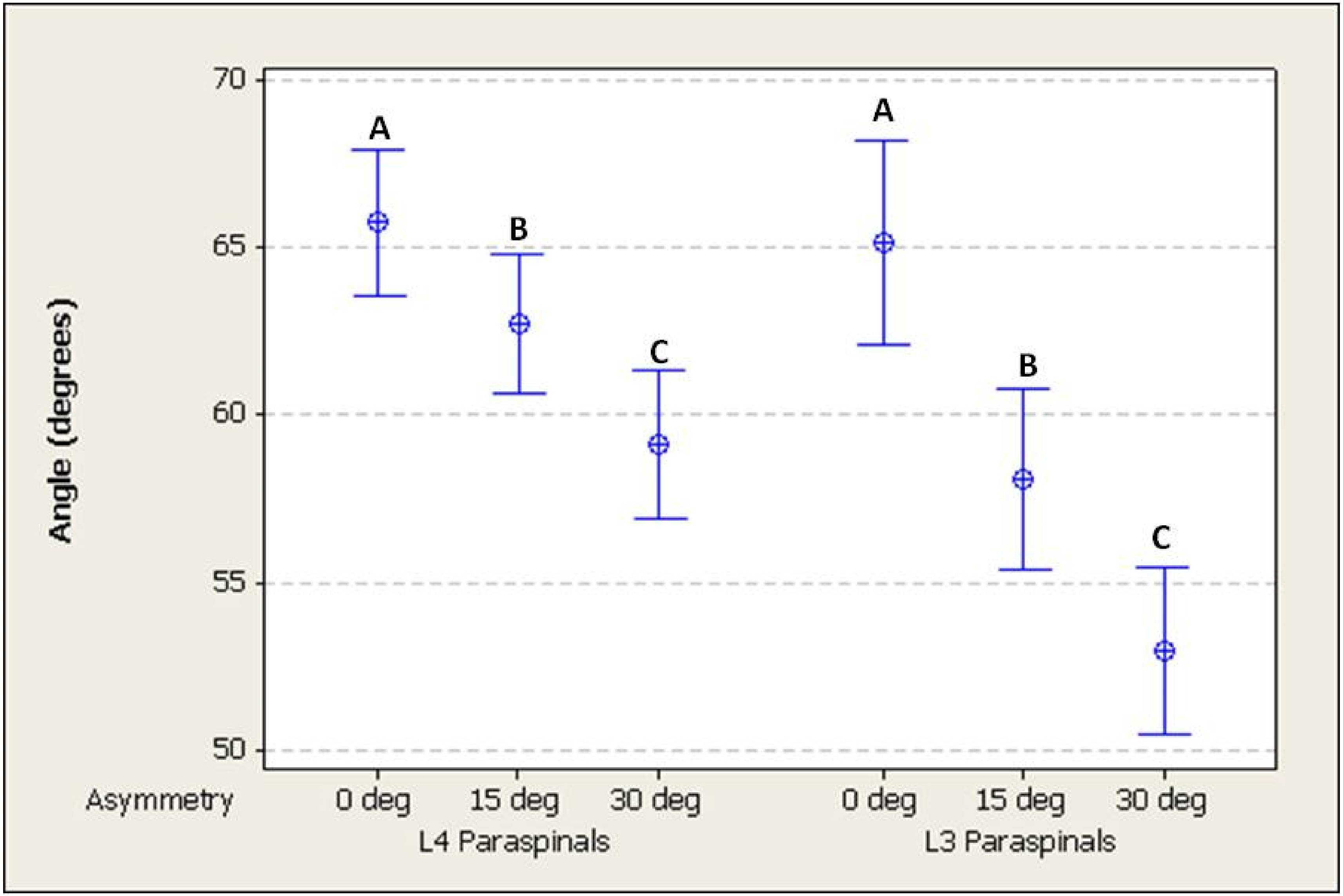

Figure 7: Trunk inclination angle at EMG-Off point for of each of the contralateral (right side) lumbar muscles as a function of asymmetry. Different letters indicate levels that are significantly different and 95% confidence interval is shown.